Discovery and History of the Electron

Introducing the Ilectron

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Abstract

The electron was the first elementary particle to be discovered. We know its observed mass, its charge, its angular momentum and we assume that it has infinite lifetime. For more than a century no consensus has been reached over the equation of motion for a radiating electron and the standard model would have us believe that the electron is a point particle. We briefly consider the history of the equation of motion of the electron and point to the reason for the failure of what was considered to be the correct result of classical physics. Furthermore, a given mass has an event horizon, and any mass approaching a point would lie within and so be a black hole, which would rapidly disappear via Hawking radiation. Because a point particle with mass cannot spin, it has been declared that the electron angular momentum is “a purely quantum mechanical effect”. The prediction of zitterbewgung (trembling motion in German) by Schrödinger offered a partial solution, in that it suggested that the angular momentum was due to circular motion around a point, but still left the problem of a massive particle (the electron) travelling at c, the speed of light. We have the rules for accelerating electrons to exist in stationary states, but no explanation as to why they do not radiate. It was known from the beginning that the electron must have mechanical mass. Unable to separate this mass it was assumed to be 'pushed into a non-observable realm'. Despite these problems and lack of explanations, Quantum Electro Dynamics (QED) continues to produce the most accurate predictions ever produced by theory.

We also consider a complex combination of charge and mass which leads to the consideration of possible 5th force and a new particle, which we call the ilectron. The ilectron has derived properties that make it a contender as a WIMP.

Electron and Bengaluru

- ☐ Electron was discovered in 1897 by JJ Thompson

  120th Anniversary

Talking of Anniversaries……

- ☐ Bengaluru was founded by Kempe Gowda in (a feudatory ruler under the Vijayanagara Empire) in 1537

  480th Anniversary

→ ***Bengaluru is 4 x as old as the discovery of the electron!***

Basic Electromagnetic Quantities

1. $\nabla \cdot \mathbf{D} = \rho_V$
2. $\nabla \cdot \mathbf{B} = 0$
3. $\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$
4. $\nabla \times \mathbf{H} = \dfrac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$

Charge and Current are the Most Basic EM quantities

Field Quantities flow from it

No magnetic monopoles yet!

So, electrons and their motion become the most fundamental quantities

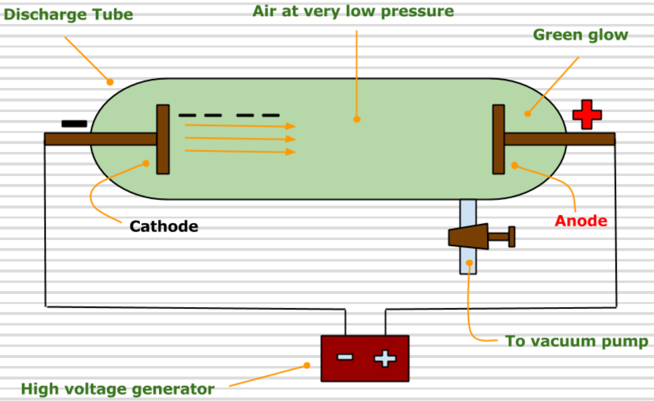
120th Anniversary of the Electron
(1897-2017 and Beyond)

☐ Joseph John Thomson

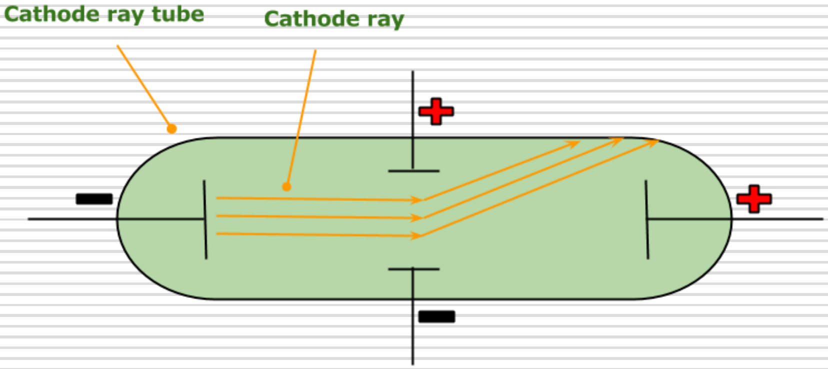
1856 – 1940
Prof. of Experimental Physics
Cavendish Laboratory,
Cambridge University, UK
Rutherford and Bohr
were his notable students!

- ✓ Nobel Prize in 1906
- ✓ 7 of his students became Nobel Laureates
- ✓ Hydrogen atom was the unit
- ✓ He suggested a more fundamental unit
- ✓ Was studying the properties of Cathode Rays
- ✓ Estimated the mass of cathode rays by measuring the heat generated when it hit a thermal junction - comparing this with magnetic deflection of the rays
- ✓ Cathode rays – much lighter than H2 atom -→ Negatively charged Electron

JJ Thomson’s Experiments and Contributions


Discharge Tube
Air at very low pressure
Green glow
Cathode
Anode
To vacuum pump
High voltage generator

Production of cathode rays


Cathode ray tube
Cathode ray

✓ Cathode ray “Particles” coming out of the Cathode
✓ Much lighter than Hydrogen atom
✓ Thomson gets e/m
✓ Millikan found the absolute value of charge
✓ Mass of electron was determined

Charge and rest mass of The Electron

- ✓ **The Electron arrived on the scene in 1897 a little too late !**

- ✓ **Units of Charge (Coulomb) and**
  Mass (Kg)
  were already defined

- ✓ **Charge and mass of the electron became miniscule**

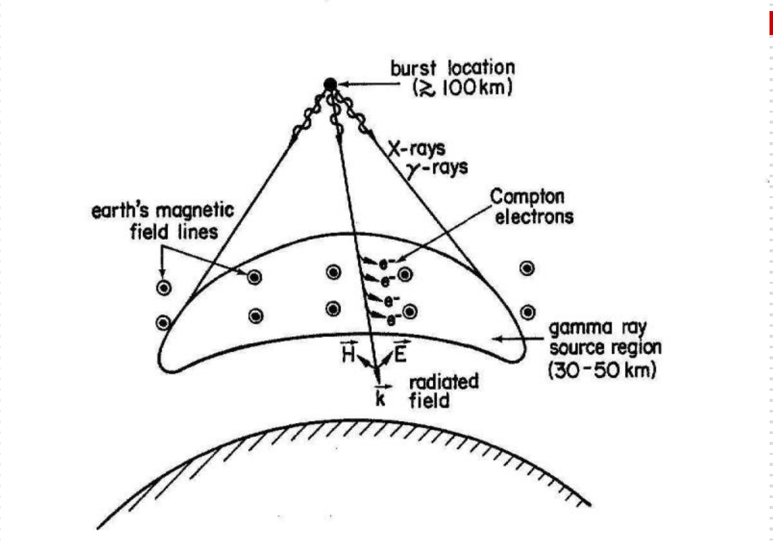
$$q_e = 1.6 \times 10^{-19}\ C$$

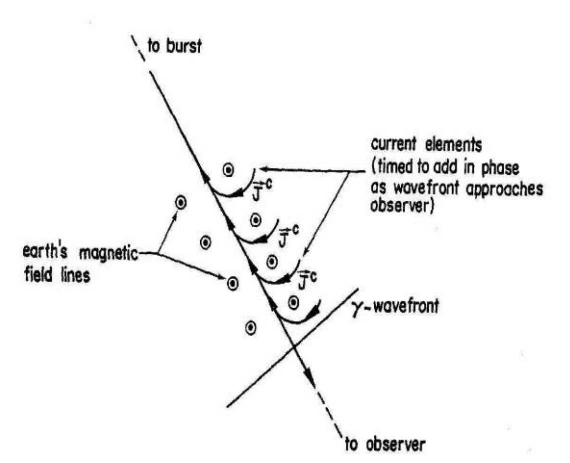
$$m_e = 9.1 \times 10^{-31}\ kg$$

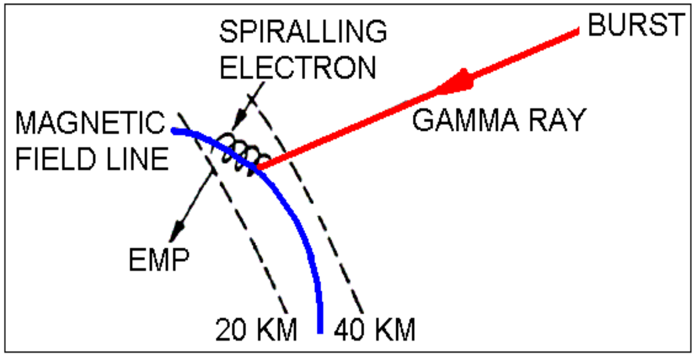
“Elementary” Particles

- ✓ **A particle is “Elementary” if it does not have an internal structure ;**
- ✓ **Electron is truly Elementary!   MDW**
- ✓ **Ref: Quarks and Gluons – A Century of Particle Charges**
  M. Y. Han(Duke University, Durham, NC, USA)

High-Altitude/Nuclear Electromagnetic Pulse
HEMP or NEMP
How the EM Pulse is Born ?


burst location
(≳ 100km)
X-rays
γ-rays
Compton
electrons
earth's magnetic
field lines
e⁻
e⁻
e⁻
e⁻
gamma ray
source region
(30-50 km)
H
E
k
radiated
field


to burst
current elements
(timed to add in phase
as wavefront approaches
observer)
J^c
J^c
J^c
earth's magnetic
field lines
γ-wavefront
to observer

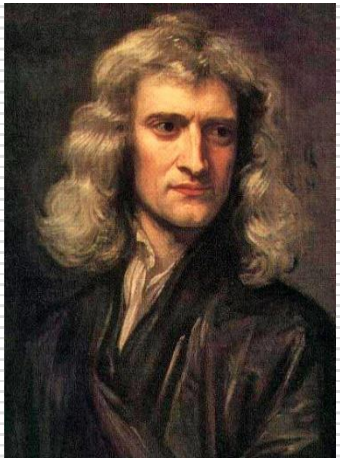

SPIRALLING
ELECTRON
BURST
GAMMA RAY
MAGNETIC
FIELD LINE
EMP
20 KM
40 KM

- ✓ Compton scattering, discovered by
  Arthur Holly Compton,
  Washington Univ, St. Louis, USA
- ✓ scattering of a photon by a charged particle,
  usually an electron.
- ✓ results in a decrease in energy (increase in wavelength) of the photon
  This is called Compton shift
- ✓ Part of the energy of the photon is transferred to the electron that recoils.

Before JJ Thomson

Newton (Gravitation)
Franklin (Electricity)
Coulomb (Electrical Force)

- Gravitational Force (always attractive force) was known
- Isaac Newton (1643 – 1727)
- Newton's Law of Gravitation



$$F = G\frac{m_1 m_2}{r^2}$$

Let us say I wish to send some resource from earth to moon

Need to know the Force – Bit of Googling …

Mass of the earth = 6×10^{24} kg

Mass of moon = 7.35×10^{22} kg

G = 6.67×10^{-11} N $(m/kg)^2$ [Cavendish in 1798]

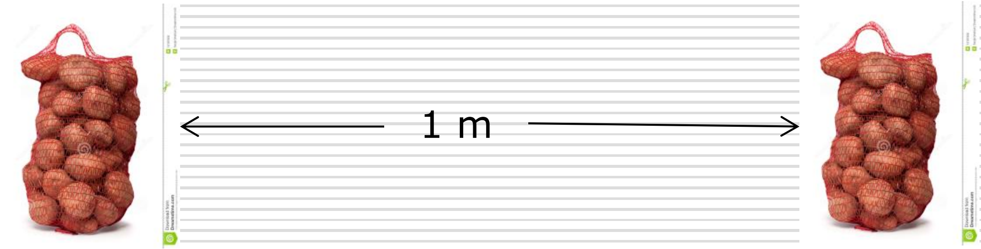
Average distance r = 3.844×10^{8} m

F = 1.99×10^{20} N

My mass = 80 kg My weight due to earth's gravity = w = mg = 80kg x 9.8n/kg = 784 N

Mass is a scalar / Weight is a vector !

$$F = G\frac{m_1 m_2}{r^2}$$



Two Objects 1 kg each, 1 m apart F = 6.67 x 10^{-11} N

Two elephants (12,000 kg each) 1 m apart F = 0.01 N

If you are sitting next to Ms. Universe, you may feel an attractive force!

Estimating the mass of the Earth

I know:

my mass $m = 80$ kg
and weight $w = mg = 784$ Newtons

and radius of the earth
r_e = earth radius = 6.37×10^6 m

$784 \text{ N} = G \times 80 \text{ kg} \times m_e / (r_e)^2$

m_e = mass of the earth = 6.6×10^{24} kg

Pretty Amazing !

Before JJ Thomson

Newton (Gravitation)
Franklin (Electricity)
Coulomb (Electrical Force)

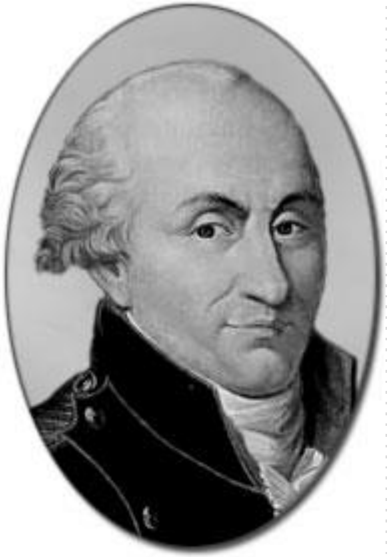
- Electricity was known
- Benjamin franklin (1706 to 1790)

- One of the Founding Fathers of USA
  leading author, printer, political theorist, politician, freemason, postmaster, scientist, inventor, civic activist, statesman, and diplomat
- Famous Kite Experiment for Lightning
- ESD Rubbing glass and Plastic
  Glass was called positive & Plastic was negative
  → Electron has negative charge
  strictly a matter of convention

Before JJ Thomson

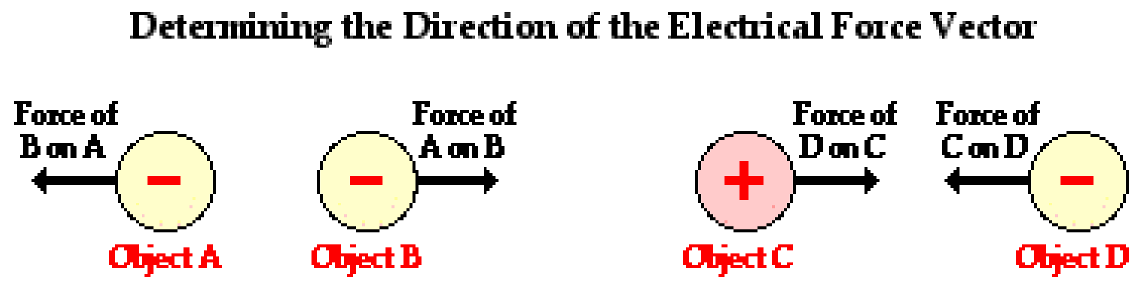
Newton (Gravitation)
Franklin (Electricity)
Coulomb (Electrical Force)

- Coulomb Force between charges was known
- Charles Coulomb (1736 to 1806)



Charles-Augustin de Coulomb
(1736-1806)

$$F = \frac{k \cdot Q_1 \cdot Q_2}{d^2}$$



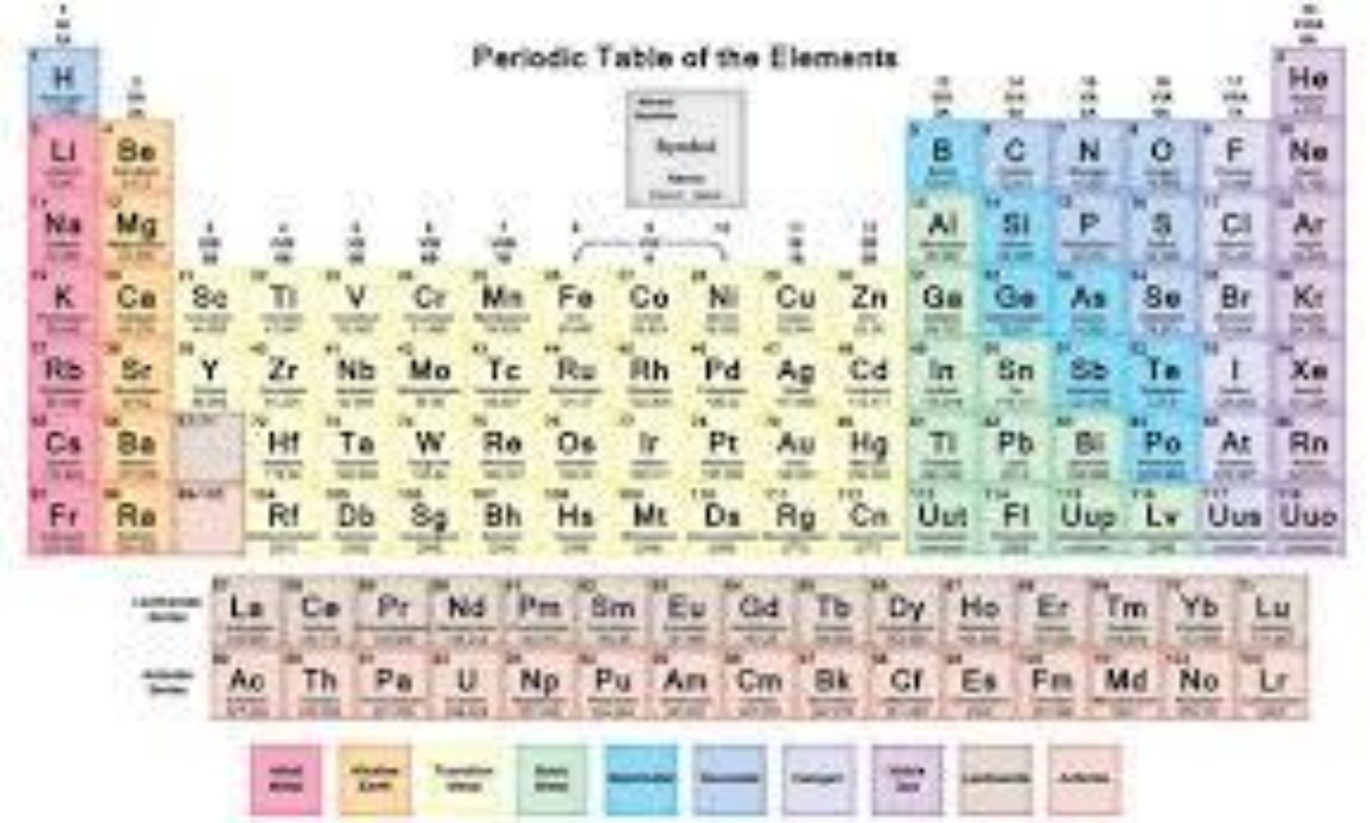
Determining the Direction of the Electrical Force Vector

Force of B on A
−
Object A
Force of A on B
−
Object B
+
Object C
Force of D on C
Force of C on D
−
Object D

Coulomb Electrical Force along with the magnetic force
N and S Poles → Electromagnetic Force

- Elements are nicely organized into Periodic Tables
- Elementary Particles are not organized

- ☐ Elements are nicely organized into Periodic Tables
- ☐ Can we organize "Elementary" Particles?

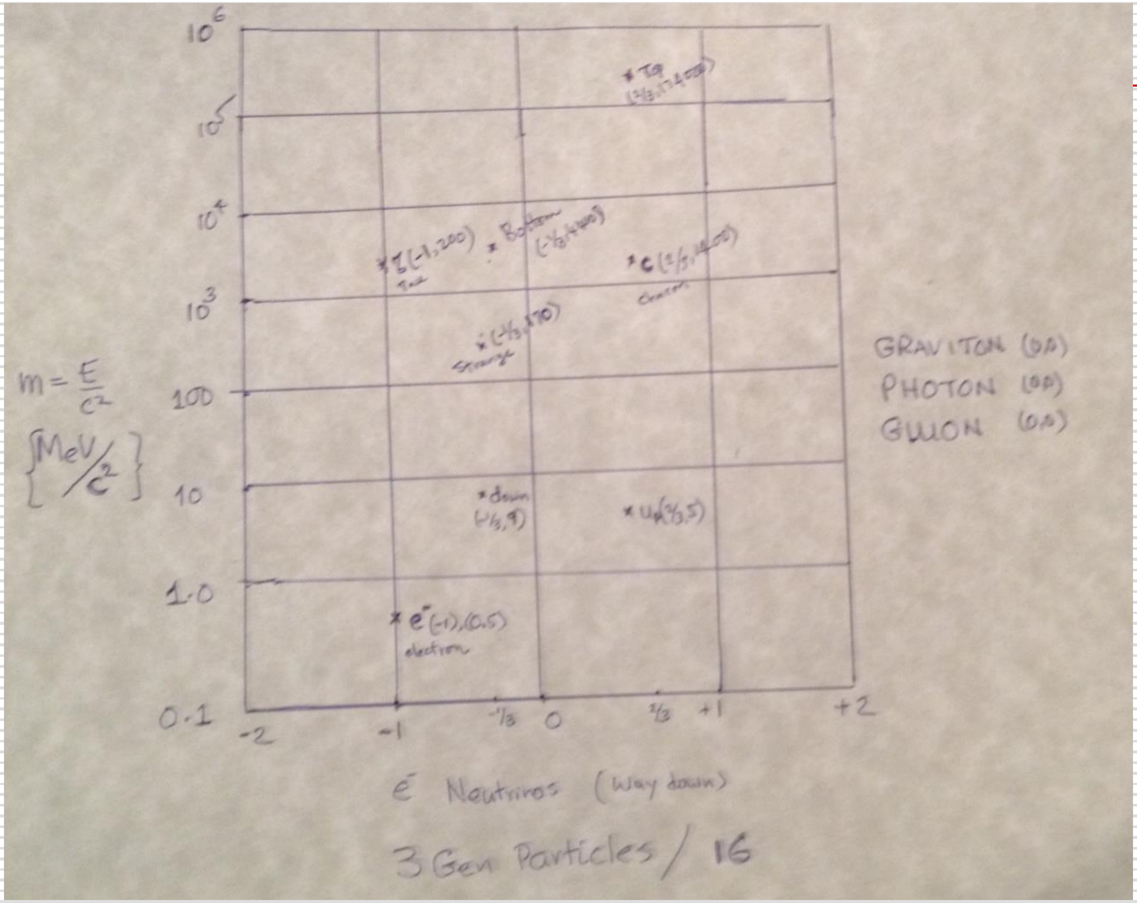


Periodic Table of the Elements

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Organizing "Elementary" Particles



Electron's sidekick - Neutrinos very little mass and charge

- Sub-nuclear particles are called Baryons
- Protons and Neutrons (most common)
- 6 Quarks (even smaller) 2 light and 4 heavy
- In the last 2 weeks a new Baryon (which was hypothesized) was fleetingly seen at LHC
- Guy Wilkinson – an Oxford Physicist announced this..
- Called χ - 2 heavy Quarks with a light one dancing around!

What is “elementary” about a particle?

- Before JJ Thomson discovered the electron (1897), Hydrogen atom was considered to be the

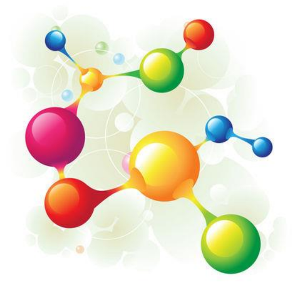
  “smallest bit of matter”

- He found a smaller bit!

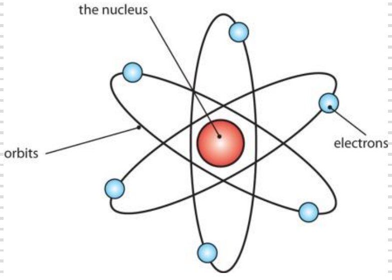
- Turned out to be *the electron*

How Important is the Electron?

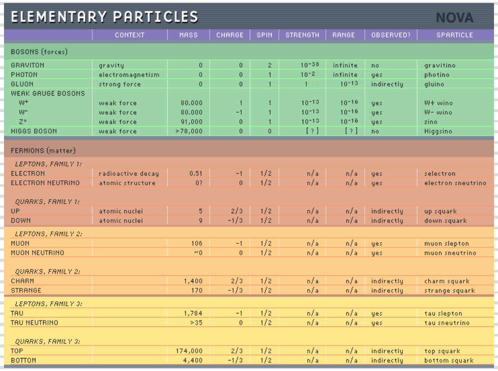
Object



Molecules



Atoms



ELEMENTARY PARTICLES

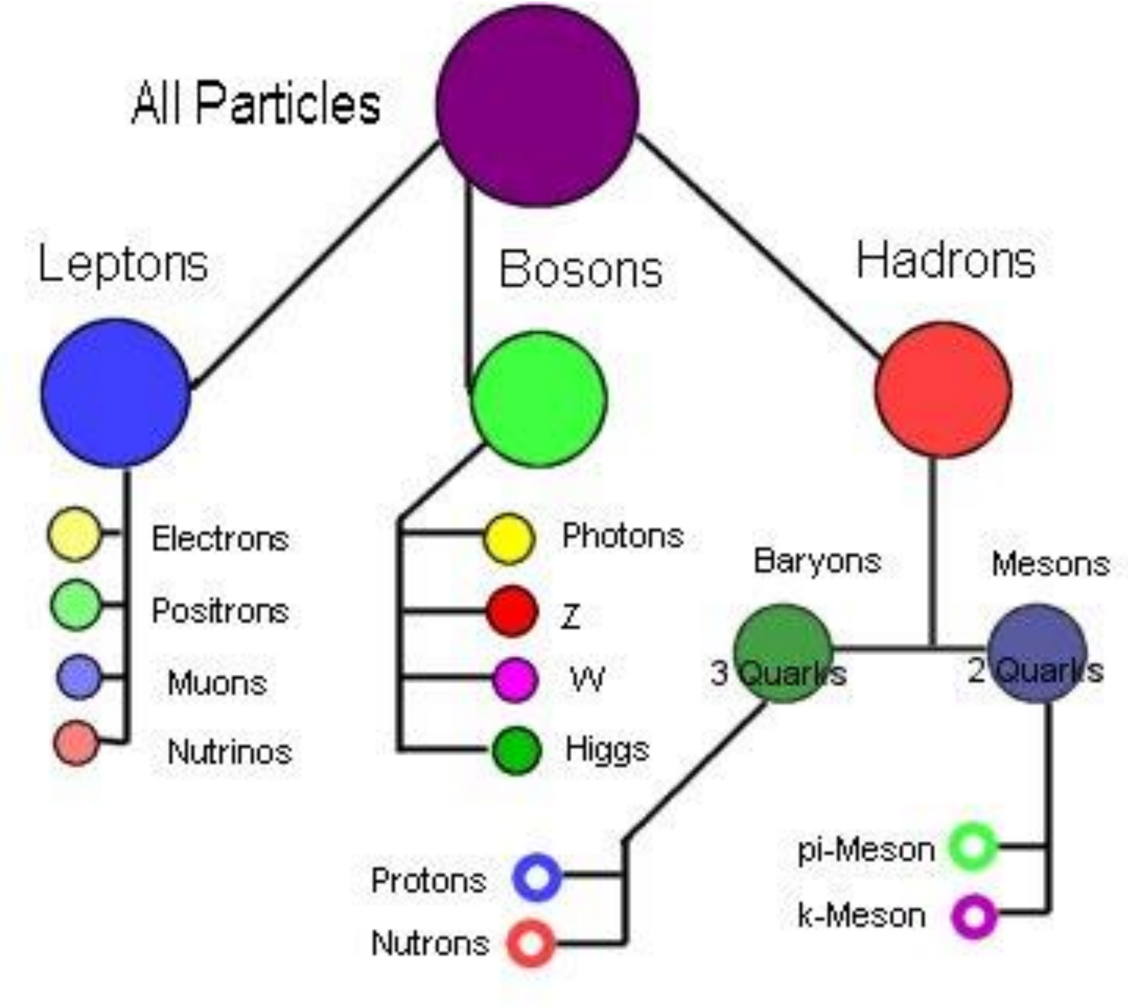
NOVA

	CONTEXT	MASS	CHARGE	SPIN	STRENGTH	RANGE	OBSERVED?	SPARTICLE
BOSONS (forces)								
GRAVITON	gravity	0	0	2	10^{-38}	infinite	no	gravitino
PHOTON	electromagnetism	0	0	1	10^{-2}	infinite	yes	photino
GLUON	strong force	0	0	1	1	10^{-13}	indirectly	gluino
WEAK GAUGE BOSONS								
W^+	weak force	80.000	1	1	10^{-13}	10^{-16}	yes	W+ wino
W^-	weak force	80.000	-1	1	10^{-13}	10^{-16}	yes	W- wino
Z^0	weak force	91,000	0	1	10^{-13}	10^{-16}	yes	zino
HIGGS BOSON	weak force	>78,000	0	0	[?]	[?]	no	Higgsino
FERMIONS (matter)								
LEPTONS, FAMILY 1:								
ELECTRON	radioactive decay	0.51	-1	1/2	n/a	n/a	yes	selectron
ELECTRON NEUTRINO	atomic structure	0?	0	1/2	n/a	n/a	yes	electron sneutrino
QUARKS, FAMILY 1:								
UP	atomic nuclei	5	2/3	1/2	n/a	n/a	indirectly	up squark
DOWN	atomic nuclei	9	-1/3	1/2	n/a	n/a	indirectly	down squark
LEPTONS, FAMILY 2:								
MUON		106	-1	1/2	n/a	n/a	yes	muon slepton
MUON NEUTRINO		~0	0	1/2	n/a	n/a	yes	muon sneutrino
QUARKS, FAMILY 2:								
CHARM		1,400	2/3	1/2	n/a	n/a	indirectly	charm squark
STRANGE		170	-1/3	1/2	n/a	n/a	indirectly	strange squark
LEPTONS, FAMILY 3:								
TAU		1,784	-1	1/2	n/a	n/a	yes	tau slepton
TAU NEUTRINO		>35	0	1/2	n/a	n/a	yes	tau sneutrino
QUARKS, FAMILY 3:								
TOP		174,000	2/3	1/2	n/a	n/a	indirectly	top squark
BOTTOM		4,400	-1/3	1/2	n/a	n/a	indirectly	bottom squark

Sub-nuclear

Basically, There is no Universe without The Electron

Classification of Particles


All Particles
Leptons
Bosons
Hadrons
Electrons
Positrons
Muons
Nutrinos
Photons
Z
W
Higgs
Baryons
Mesons
3 Quarks
2 Quarks
Protons
Nutrons
pi-Meson
k-Meson

Electron

- ✓ **One of the most abused and used particles of nature**
- ✓ **Kicked around**
- ✓ **Accelerated to 99.999% of the speed of light**
- ✓ **Origin of electricity**
- ✓ **Integral part of Maxwell's Equations**
- ✓ **A microscopic understanding of the motion of electrons**
  - **semi- conductors**
  - **high-tech , IT**
  - **Lasers**
  - **super conductors**
  - **Opto-electronics**
  - **Photonics**

➢ **Electron e^- is the quantum of electric charge**
Photon γ is the quantum of radiation

A quick Example of the Abundant Nature of Electrons

- ✓ When I turn ON this clicker

400 μA of current flows

= electrons/s

= N x 1.6 x 10^{-19} /s

N = 400 x 10^{-6} / [1.6 x 10^{-19}]

= 2.5 x 10^{13}

= 2.5 Peta

= 2.5 Quadrillion

Mass and Energy

In the Newtonian Scheme.. Mass = measure of inertia or quantity of matter that resists its motion

Mass and Energy have distinct and separate Identities

Einstein's most Famous Equation $E = m c^2$

Mass and Energy

2 sides of the same coin

related by c^2 =
90 Quadrillion $(m/s)^2$

INDIA
100 RUPEES
75 YEARS OF DANDI MARCH
1930-2005
Reverse/Tail
Obverse/Head

Doesn't have to move , just have mass
This equation gave rise to Nuclear Power

Value of Speed of Light from Rig Veda

A Sanskrit Verse that goes back to Rig Veda

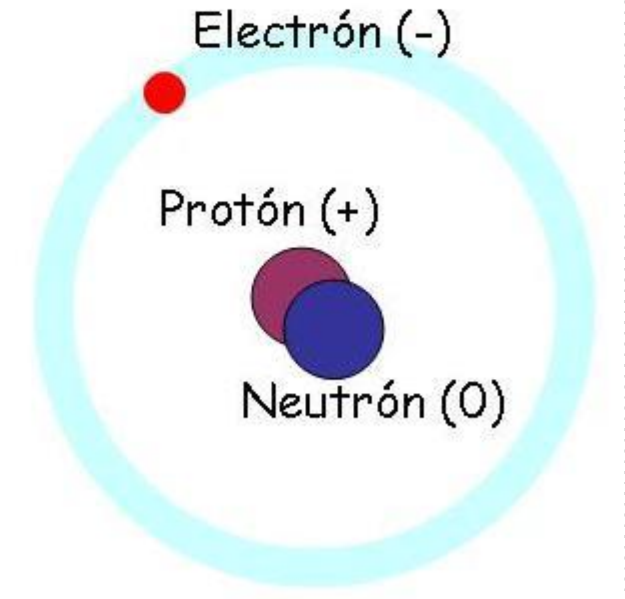
tatha ca smaryate yojananam. sahasre dve dve sate dve ca yojane ekena nimishardhena kramaman.

This means "It is remembered here that Sun (light) traverses 2,202 yojanas in half a nimisha."
Nimisha = (16/75) s

= 2,202 x 9.09 miles per 0.1056 seconds
= 20,016.18 miles per 0.1056 seconds
= 189,547 miles per second = 3.032 x 10^8 m/s

The Best Measurement we have is by bouncing light off of a mirror left on moon → c = 2.997924562 x 10^8 m/s

Simplest Atom Hydrogen



Attribute	Fundamental “Particle” – the electron
rest mass m_o	$9.10938188\ 10^{-31}$ kg
charge (- q)	$1.602176462\ 10^{-19}$ C
classical radius	$2.81795518\ 10^{-15}$ m
quantum mechanical radius	0
Angular momentum $\Omega = \hbar / 2$	$5.27285\ 10^{-35}$ kg m^2 /s
magnetic moment	$9.27400899\ 10^{-24}$ J/T

Hydrogen Atom

All quantities are known from measurement except the radius

Radius of the electron

Equate electric field energy to kinetic energy

$$m_0 c^2 = \frac{1}{4\pi\varepsilon_0}\int_{r_e}^{\infty}\frac{q^2}{r^2}\,dr = \frac{q^2}{4\pi\varepsilon_0 r_e}$$

$$r_e = \frac{q^2}{4\pi\varepsilon_0 m_0 c^2}$$

$= 2.81 \times 10^{-15}$ m

- just an order of magnitude
- Quantum Physics says an electron is both a point particle and a wave – Particle –Wave Duality
- zero radius would imply infinite electrostatic energy for a free electron

Angular Momentum of the Electron

- Measurements and the Dirac Equation confirms that electron has angular momentum

Physics Notes

Note 22

09 December 2016

The Electron and the Ilectron

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and

C. E. Baum
(Posthumously – based on our conversations with him before he left us)

The “Complex” Electron

- **Electron has charge and Mass**
  Can we combine the two?

Consider Two Electrons

- Electrostatic and Gravitational Force between two electrons…

$$f_q = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2} = \frac{K q_1 q_2}{r^2} \qquad f_m = -\frac{m_1 m_2}{4\pi g r^2} = \frac{-G m_1 m_2}{r^2}$$

Define two constants

$$d_1 = \sqrt{\frac{\varepsilon_0}{g}} = 0.861x10^{-10} \ (C/Kg) \quad and \quad d_2 = \sqrt{\frac{g}{\varepsilon_0}} = 1.16 \, x \, 10^{10} \ (Kg/C)$$

$$d_3 = \frac{q}{m_o} d_2 = \frac{q}{m_o}\sqrt{\frac{g}{\varepsilon_o}} = \frac{1.6x10^{-19} \ C}{9.1x10^{-31} Kg} d_2 = 1.75x10^{11} d_2 = 2.03x10^{21}$$

This is a “new” dimensionless constant for the electron

“New” Constant d_3

- For the electron $d_3 = 2.03 \times 10^{21}$
- This approach can be extended to all particles – say proton and neutron.
- This constant would vanish for a neutral particle ($q = 0$)
- We now have a way to put charge and mass in the same units!

Complex Mass or Complex Charge

Many ways to do this!

$$M = m + iqd_2 = m + iq\sqrt{\frac{g}{\varepsilon_o}}$$

$$Q = q + imd_1 = q + im\sqrt{\frac{\varepsilon_o}{g}}$$

Looks a bit strange, but this is preferred

$$M = \frac{m}{\sqrt{g}} + i\,\frac{q}{\sqrt{\varepsilon_o}}$$

$$Q = \frac{q}{\sqrt{\varepsilon_o}} + i\,\frac{m}{\sqrt{g}}$$

Consider Two “Complex” Masses

$$M_1 = \frac{m_1}{\sqrt{g}} + i\,\frac{q_1}{\sqrt{\varepsilon_o}} \qquad \text{and} \qquad M_2 = \frac{m_2}{\sqrt{g}} + i\,\frac{q_2}{\sqrt{\varepsilon_o}}$$

Complex Force between these Complex Masses is given by

$$F_M = \frac{-M_1 M_2}{4\pi\, r^2} \qquad F_M = \left\{-\frac{m_1 m_2}{4\pi\; g\, r^2} + \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}\right\} - i\,\left\{\frac{m_1 q_2 + m_2 q_1}{4\pi\sqrt{g\varepsilon_0}\, r^2}\right\} = f_m + i\; f_{im}$$

Note that the real part gives the conventional gravitational and Coulomb forces,

Imaginary part .... ?

If we now choose M_2 to be a neutral particle by setting $q_2 = 0$

- ☐ One of the terms in the imaginary force vanishes

$$F_M^* = f_m - i \left\{ \frac{m_2\, q_1}{4\pi \sqrt{g\, \varepsilon_0} r^2} \right\}$$

Setting

$$q_1 = m_{im} \sqrt{\frac{\varepsilon_0}{g}}$$

$$F_M^* = f_m \overset{\times\times 10^{-21}}{+} i\, f_{im}$$

$$f_{im} = -\frac{m_2 m_{im}}{4\pi\, g\, r^2}$$

In some normalized sense, comparing this Electro-mass force o other 4 forces

Strong	Weak	Electro Magnetic	Imaginary Electro- Mass	Gravity
1	0.18	0.18	0.063	23.6 $\times 10^{-35}$

Strong and Weak forces do not exist outside the nucleus

“The Ilectron”

Recognizing that imaginary mass can be interpreted as charge, and imaginary charge as mass,

We can consider the imaginary electron, where we interchange the mass and charge, but this transformation is not merely an algebraic transform.

We must transform the intrinsic mass of the electron to obtain the new charge,

the charge transforming as before.

Introducing The Ilectron

Evaluating the components

Intrinsic mass equivalent of electron’s charge

$$m_{ii} = q_e \sqrt{\frac{g}{\varepsilon_0}} = 1.86 \times 10^{-9} \text{ kg}$$

Intrinsic charge equivalent of electron’s mass

$$q_i = m_i \sqrt{\frac{\varepsilon_o}{g}} = \frac{m_0}{3.2635} \sqrt{\frac{\varepsilon_0}{g}}$$ = 2.17 x 10-41 C

We are calling this new particle with its mass and charge given above as the “ilectron” or an “imaginary electron”.

- like the I-phone or I-Pad

Spin and Magnetic Moment of the Ilectron

- We have estimated these quantities.
- One of the reviewers said “mere speculation”
- Sure… but where would science be if we don’t break from what is known once in a while.

Analogous Look at The Electron and a Blackhole

- Recall we had the classical radius of the electron

$$r_0 = \frac{q_e^2}{4\pi\varepsilon_0 m_0 c^2} = 2.817\, x\, 10^{-15} m$$

Replacing $q_e / \sqrt{\varepsilon_0}$ in the above, by $m_0 / \sqrt{g}$

the radius of the electron is given by $r_0 = \frac{m_0}{4\pi g c^2}$

The above formula for the radius of an electron is similar to the formula for the radius of a Schwarzschild black hole

$$r_s = \frac{m}{2\pi g c^2}$$

Examples of Schwarzschild radii of some common planets are:

Sun (3 km), Earth (8.7 mm),
Moon (0.11 mm) and Jupiter (2.2m).

If the Schwarzschild radius exceeds the physical radius, the object is a black hole. Hence these planets are not black holes.

Alternatively,

- We can calculate the Schwarzschild radius of the electron

$$r_{es} = \frac{m_e}{4\pi\, g\, c^2} = 6.76 \times 10^{-58}\, m$$

Much less than the "physical" radius of 2.82 x 10^{-15} m

→ Electron is not a Black hole ..... Thank God !

Summarizing Remarks

- By forming a complex electron, we have raised the possibility of an Electro-mass force much weaker than EM Force, but orders of magnitude > Gravitational force
- A hypothetical imaginary electron has been constructed
- It has almost no charge (no magnetic moment) but is MASSIVE ~ ~1.9 10^{-9} kg
- This mass converts to 10^{15} TeV using $E = m c^2$
- The maximum energy of the LHC in CERN is 13TeV. The LHC would have to be upgraded by a factor of around $8x10^{13}$ to produce an ilectron! ……. Absolutely no chance to find it.

  That is a bit disappointing!
- At this time the only possibility of confirmation is if the ilectron meets its anti-particle, the ipositron and the resulting gammas pass through our detectors.
- Gammas above 100 TeV are classified as ultra-high energy, and so far none have been detected.

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What Next?

- Question Raised by Prof. Tai Tsun Wu
  - High Energy Theoretical Physicist at CERN and Harvard University after he read our Paper

Maxwell’s Equations characterize *EM Waves*

Dirac Equation characterizes *The Electron*

What is the Equation that Characterizes *The Ilectron?*